## COUNTERMEASURES TO ADDRESS FAR-SIDE CRASHES: FIRST RESULTS

**Brian Fildes**
Monash University Accident Research Centre, Melbourne, Australia

**Ola Bostrom**
**Yngve Haland**
Autoliv Research, Sweden

**Laurie Sparke**
Holden, Melbourne, Australia

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## ABSTRACT

This study set out to compare a number of counter-measure options to restrain drivers in far-side crashes using the modified BioSID crash test dummy. The findings showed that 3-point belts alone were not sufficient for far-side occupant protection. Attaching double (buckle and belt) pretensioners to the std. 3-point belt also failed to improve protection substantially. The cross-belt configuration did improve protection but not as much as the inclusion of an additional side support. However, even the best restraint combination employed here would probably not provide optimal protection for two occupants. Further research is warranted to improve far-side occupant kinematics and far-side restraint systems.

## INTRODUCTION

Side impacts are frequent and extremely harmful crashes. Twenty five percent of vehicle casualties (28 percent of fatalities) occur from these crashes, accounting for roughly one-third of occupant Harm on our roads (Fildes, Lane, Lenard & Vulcan, 1994). The likelihood of being killed or seriously injured is very high in side impact crashes.

Current side impact regulations in Europe, the USA, Japan and Australia specify acceptable performance levels for a single crash configuration and impact speed for near-side occupants. This is appropriate as near-side crashes are extremely common and harmful to occupants involved in side impact collisions. Fildes, et al, 1994; Frampton, Brown, Thomas and Fay (1998); and Digges and Dalmotas (2001) all reported that near-side occupants account for up to 70% of all side impact injuries. However, far-side occupants are involved in 30% of injuries and up to 40% of occupant Harm in real-world side impact crashes (Fildes, Gabler, Fitzharris. & Morris, 2000). This seating position and Harm is currently not addressed by existing vehicle safety initiatives around the world. Optimal benefits across all side impact crash types and impact speeds require attention be given to both near-side and far-side occupants in future efforts and regulations.

Previous research undertaken in Australia (Fildes, Sparke, Bostrom, Pintar, Yoganandan and Morris 2002) identified a number of strengths and weaknesses with existing side impact test dummies for far-side occupant protection. It concluded that while there was scope for improvement in dummy design for far-side crash testing, a BioSID dummy with a modified lumbar spine unit gave reasonably similar results to those of a human specimen during the early phases of occupant kinematics. Hence, it was judged suitable for developing countermeasures immediately aimed at restraining the far-side occupant in the seat.

## METHOD

This study set out to compare a number of countermeasure options to restrain drivers in a far-side crash using the modified BioSID crash test dummy. Crash testing was carried out at Autoliv's crash test facility in Australia using a pre-deformed cockpit of a Holden Commodore fitted out with a driver's seat and console but no passenger seat. The cockpit was constructed from a pre-deformed Commodore vehicle that had been involved in an earlier side impact crash test. The test buck was attached to a sled and used in a bending bar sled test designed to replicate the full-scale test (the sled test setup had been validated against full car crash tests and reported in Bostrom, Judd, Fildes, et al., 2002). All tests adopted the ECE95 test procedure using a Holden Commodore vehicle and the European MDB but at a higher 65km/h test speed. Figure 1 shows the test buck fitted to the sled.

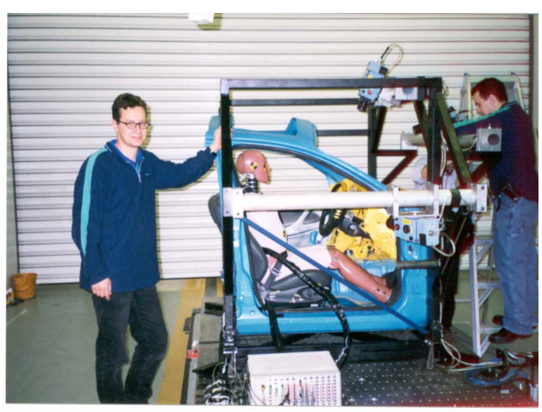

**Figure 1 Pre-deformed test buck used in the sled test series**

### Test Dummy

A 50% Male BioSID test dummy that had been fitted with a modified spring spine unit was used in the tests. An earlier trapezoid spine unit had been shown to give reasonable kinematics to that of a human cadaver (Fildes, Sparke, Bostrom, Pintar, Yoganandan & Morris, 2002) although it had two shortcomings; limited crash directions (90deg only) and no spine elongation capability. Hence, a new spine unit was subsequently developed comprising a central spring unit with flanges that overcome these limitations (see Figure 2). Subsequent testing showed this to be superior to the original trapezoid unit (Fildes, Bostrom Haland and Sparke, 2003).

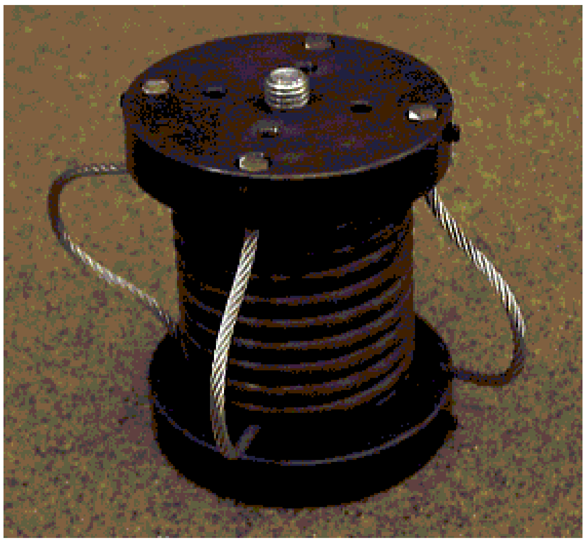

**Figure 2 Spring-spine unit**

### Test Conditions

The sled was fitted with the test buck and driver dummy and impacted the bending bars at 24km/h to give the required crash pulse. Tests were carried out with the test buck set at 90deg and 60deg to the direction of impact. Four countermeasure options were tested at 90deg and two at 60deg as detailed below.

<u>90deg impact</u>

- **Test 90-1**: Std 3-point seatbelt (no pretensioners)
- **Test 90-2**: Std 3-point seat belt (with both buckle and retractor pretensioners)
- **Test 90-3**: Std 3-point seatbelt plus an extra (reversed configuration) 2-point cross-belt, both fitted with buckle pretensioners (Figure 3).
- **Test 90-4**: Std 3-point seatbelt (with buckle pt) plus a side support welded to the inside of the seat frame just below the shoulder position (Figure 4).

<u>60deg impact</u>

- **Test 60-1**: Std 3-point seat belt (no pretensioners)
- **Test 60-2**: Std 3-point seatbelt (buckle pt) + side support

Figures 3 and 4 shows the cross belt and seat side support arrangements.

**Figure 3 Cross-belt arrangement**

**Figure 4 Seat side support arrangement**

### Belt Specifications

The 3-point belt was the standard unit normally fitted to the Holden Commodore and was retractor-pretensioned in test 90-2 and buckle-pretensioned in all tests except for 90-1 and 60-1. The extra 2-point belt was buckle pretensioned in test 90-3. For the cross-belt configuration, the 2-point retractor was attached to the top of the seat frame.

## RESULTS

Table 1 lists the measures of interest obtained from the modified BioSID test dummy for both the 90deg and 60deg crash tests.

**Table 1 Dummy measures obtained from the 6 crash tests**

| Test | HIC | MVy (head) | MVz (head) | Fz (comp) | Fz (tension) | Nij | F-DI |
|---|---|---|---|---|---|---|---|
| _90deg tests_ | | | | | | | |
| 90-1:Std 3-point seatbelt | 524 | 9.5m/s | 6.3m/s | 3.2kN | 1.8kN | 0.85 | 0 |
| 90-2: 3pt belt + pretension | 342 | 8.3m/s | 6.0m/s | 4.4kN | 2.1kN | 0.78 | 0 |
| 90-3: 3pt belt + 2pt belt | 156 | 7.9m/s | 6.8m/s | 0.02kN | 1.4kN | 0.21 | 1.1kN |
| 90-4: 3pt belt + side support | 34 | 6.8m/s | 3.0m/s | 0.01kN | 1.3kN | 0.25 | 0 |
| _60deg tests_ | | | | | | | |
| 60-1: Std 3-point seatbelt | 22 | 6.6m/s | 6.8m/s | 2.2kN | 1.0kN | 0.55 | 0 |
| 60-2: 3pt belt + side support | 14 | 5.3m/s | 6.3m/s | 0.01kN | 0.3kN | 0.07 | 0 |

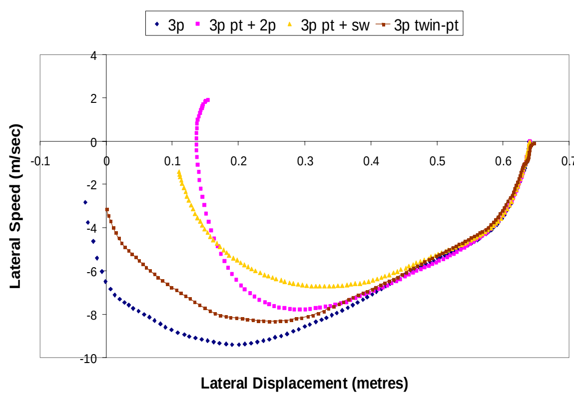


**Figure 5 MVy test results (90deg tests)**

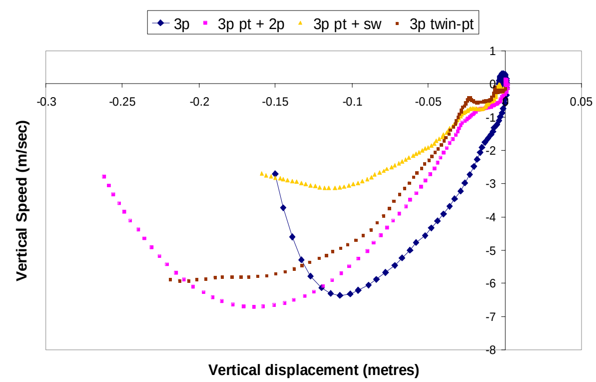


**Figure 6 MVz test results (90deg Tests)**

**90deg Impacts**

Figures 5 & 6 show the head-to-sled lateral and vertical speed by displacement results obtained from the modified BioSID test dummy for the 4-90deg far-side counter-measure tests.

<u>3-point Belt alone</u>

In the 3-point seatbelt test, the test dummy experienced a full lateral excursion to the far-side and impacted the B-pillar. HICmax. was 524 at the moment of impact and maximum speed was 9.5m/sec laterally and 6.3m/sec downward vertically during its travels.

Maximum z-loads to the neck measured at T1 were 3.2kN in compression and 1.8kN in tension. The computed Nij reading was 0.85 for this baseline countermeasure strategy.

<u>3-point Belt with Double Pretenstioners</u>

The countermeasure strategy of adding retractor and buckle pretensioners resulted in a gentler head strike to the B-pillar (HICmax. of 342) and slightly lower MVy (8.3m/s) and MVz (6.0m/s) readings.

The neck loads though were higher in both compression (4.4kN) and tension (2.1kN) although Nij was slightly diminished at 0.78.

<u>3-point and 2-point cross belt (buckle pretensioners)</u>

The next countermeasure strategy comprised a std. 3-point belt system with an additional 2-point "cross" belt, both fitted with buckle pretensioners. This configuration restrained the dummy sufficient enough to prevent a head strike with the B-pillar and a lessor HICmax. of 156. Maximum lateral velocity was reduced to 7.9m/s although vertical velocity was higher at 6.8m/s.

Neck loads reduced substantially with this configuration with Fz (compression) down to 0.02kN and Fz (tension) to 1.4kN. Nij also reduced to 0.21 although here, the resultant neck shear load (F-DI) was a positive 1.1kN.

3-point belt (buckle pt) plus side wing

The final countermeasure option considered for a 90deg crash was a 3-point seatbelt (with a buckle pretensioner) and a side support, welded to the inside of the seat.

Again with this configuration, there was no head contact with the B-pillar or the struck door (the dummy movement to the far-side was reduced) with a resultant maximum head injury criteria (HIC) of only 34. Maximum velocity was 6.8m/s laterally and 3.0m/s vertically.

Neck injury criteria also reduced with Fz (compression) = 0.02 kN, Fz (tension) = 1.3kN and Nij = 0.25.

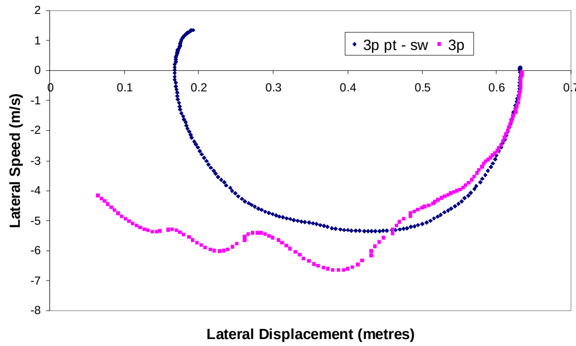


**Figure 7 MVy test results (60deg tests)**

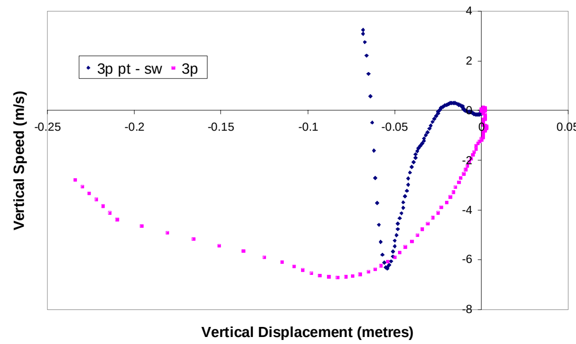


**Figure 8 MVz test results (60deg tests)**

**60deg Impacts**

Figures 7 and 8 show the head-to-sled lateral and vertical speed by displacement results obtained from the modified BioSID test dummy for the 2-60deg far-side counter-measure options tested.

3-point Belt

Based on the previous findings, only 2-counter-measure options were tested for the 60deg tests. The first was a 3-point belt alone condition as baseline.

The results in Figure 7 show that there was a full head excursion with a very mild head swipe against the struck door (HICmax = 22). The maximum lateral speed was 6.6m/s with a max. vertical speed of 6.8m/s.

Neck injury measures comprised Fz (compression) of 2.2kN and Fz (tension) of 1.0kN. The Nij was 0.55.

3-point belt (buckle pt) plus side wing

The second countermeasure strategy examined in the 60deg tests was again, a 3-point seatbelt (with a buckle pretensioner) and a side support, welded to the inside of the seat.

These results are very impressive. They show a head trajectory without B-pillar contact (maxHIC = 14) and lower values of head-to-sled lateral and vertical speed (5.3 and 6.3m/s). The neck injury measure for Fz (comp) was 0.003, for Fz (tension), 0.3kN and Nij = 0.07. All measures show a substantially improved outcome for this countermeasure option apart from the relatively high MVz measure.

**Dummy Kinematics**

Video recordings were taken of each of the 6 far-side crash tests reported above to examine the dynamic consequences of each countermeasure strategy.

For each of the 90deg tests, the film clips showed that the dummy was not contained adequately within its seat. While there were apparent improvements in the dummy injury measures for the head and neck, these would have been mitigated substantially had there been a second occupant in the near-side position.

**Figure 9 Maximum head displacement in test 90-4**

The dummy's head lateral excursion was confined, at best, to approximately 50cm from the centre of the passenger seat with the pretensioned seat belt and the side support (the distance from the centre of the seat to the deformed B-pillar was 65cm). However, this would have taken the occupant well into the space occupied by the second occupant (see Figure 9). For the 60deg tests, the lateral containment was about the same for the same countermeasure options.

Vertical displacements were less dramatic but nevertheless, still significant. The dummy's head was seen to travel up to 25cm vertically downwards in both the 90deg and 60deg tests when there was contact with the intruding near-side B-pillar. Without contact, downward displacement was still around 15cm. Moreover, there was considerable rotational movement of the dummy's head and shoulders in the space where the near-side passenger would have been. This would almost certainly have resulted in occasional occupant-to-occupant contacts when both front seats were occupied.

**DISCUSSION**

These results reveal some very interesting findings for improved far-side occupant protection in a side impact crash.

First, it was apparent from these results that the standard 3-point seat belt is not sufficient alone for providing occupant protection in the far-side seating position. In these relatively severe crashes, the far-side occupant with a conventional 3-point seat belt was propelled laterally across the vehicle towards the impacting object and struck the deformed B-pillar around the top of the door. The lap section of the belt offered no restraining capabilities whatsoever for the dummy kinematics.

In addition, firing both a buckle and a retractor pretensioner fitted to the seatbelt early in the crash cycle added little to the dummy kinematics or the restraining properties of the sash belt. While there was some sign of reduced lateral speeds in 90deg crashes, the dummy still struck the deformed B-pillar, albeit with a lower lateral acceleration.

It was only when the seat belt was supplemented with a cross-belt (an additional 2-point sash belt running diagonally opposite to the original belt) or a side support on the inside of the far-side occupant seat just below shoulder level that the far-side occupant trajectory was reduced and head contact against the B-pillar was eliminated. However, even with these additional restraining features, it was not possible to contain the dummy within its own seat.

The best restraining combination tested here for far-side occupants was a 3-point seat belt, fitted with a buckle pretensioner and a seat side support. Dummy trajectory was minimised, lateral velocity was reduced, and neck loads were substantially less for both 90deg and 60deg crash configurations. In spite of this, however, even this countermeasure strategy failed to constrain the occupant sufficiently within its seat to prevent the likelihood of contact with the near-side occupant (the trajectory traces showed considerable movement within the space that would have been occupied by the near-side passenger).

These findings are consistent with those reported from in-depth real-world crash studies (Fildes, Vulcan, Lane & Lenard, 1994; Frampton, Brown, Thomas & Fay, 1998; Digges & Dalmotas 2001). Severe head injuries were predominant for far-side impacted occupants and roughly one-third of all severely injured side impact occupants sustained their injuries at an impact severity of 27km/h or less. The dummy measures reported here concur with these injury reports for these crash severities.

Digges and Dalmotas (2001) performed full-scale side impact crashes with different belt systems. They noted that for all three belt systems tested, the dummy slipped out of the sash belt in the manner described here. While they found low injury readings, they claimed that the test configuration they used was subsequently shown to be not representative of the crashes that produce severe injuries in the real world. This is not the case with the tests conducted in this study, where 65km/h 90deg and 60deg crashes were targeted as Harmful crashes based on in-depth studies (Fildes et al, 2000).

In contrast to the findings here for pretensioners, Stolinski et al (1999) did report that firing belt pretensioners significantly reduced lateral excursion for far-side occupants in a side impact crash test. However, he used a combination of Hybrid III and US-SID test dummies, which were not validated for these crash types.

Kallieris and Schmidt (1990) tested reversed seat belt geometry using human cadavers seated on the far-side in the rear and concluded that this reversed belt configuration did prevent large lateral displacement of the upper part of the torso. Lateral excursion was also reduced in this series of tests with the cross-belt configuration, although it was argued that a superior result was still obtained for a seat side support with buckle pretensioner.

**Further Research**

The results from this series of tests were promising for improving far-side occupant protection in a side impact collision. However, while some improvement was evident by the use of the countermeasure options employed here, the results were far from optimal especially for crashes involving both near-side and far-side occupants. There is clearly a need for further research in the development of effective far-side countermeasure options as noted below.

- More extensive research is required of countermeasure effectiveness for a range of impacts aimed at keeping the far-side occupant restrained in their seat;
- A closer examination of near- and far-side occupant kinematics and interactions is warranted to understand the likely implications of far-side countermeasures;
- The *Spring Spine* offered improvements in the kinematics of BioSID over the standard unit and the trapezoid modified version. However, this needs to be evaluated further for a range of different crash types and impact speeds
- Finally, there is an urgent need to understand the neck, chest and abdominal consequences of far-side protection measures in more detail. The measures included in this series of tests were useful for evaluating countermeasure options but not for specifying the likely injury outcome of these treatments for humans.

## CONCLUSION

The findings from this study showed that 3-point belts alone are not sufficient for far-side occupant protection. Attaching double (buckle and belt) pretensioners to the std. 3-point belt also failed to improve protection substantially. The cross-belt configuration did improve protection but not as much as the inclusion of an additional side support. However, even the best restraint combination employed here would probably not provide optimal protection for two occupants. Further research is warranted to improve far-side occupant kinematics and far-side restraint systems

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